# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE

No. 1588

# INVESTIGATION OF EFFECTIVENESS OF AIR-HEATING A HOLLOW STEEL PROPELLER FOR PROTECTION AGAINST ICING

## III - 25-PERCENT PARTITIONED BLADES

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Washington
May 1948

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## SUMMARY

The icing protection obtained from an internally air-heated propeller blade partitioned to confine the heated air forward of 25-percent chord was investigated in the NACA Cleveland icing research tunnel. A production-model hollow steel propeller was modified with an internal radial partition at 25-percent chord and with shank and tip openings to admit and exhaust the heated air. Temperatures were measured on the blade surfaces and in the heated-air system during tunnel icing conditions. Heat-exchanger effectiveness and photographs of ice formations on the blades were obtained.

Surface temperature measurements indicated that confining the heated air forward of the 25-percent chord gave a more economical distribution of the applied heat as compared with unpartitioned and 50-percent partitioned blades, by dissipating a greater percentage of the available heat at the leading edge. At a propeller speed of 850 rpm, a heating rate of 7000 Btu per hour per blade at a shank air temperature of 400° F provided adequate icing protection at ambient-air temperatures of 23° F but not at temperatures as low as 15° F. With the heating rate used, a heat-exchanger effectiveness of 77 percent was obtained as compared to 56 percent for 50-percent partitioned and 47 percent for unpartitioned blades.

## INTRODUCTION

The internal passage of heated air through propeller blades for protection against icing has been previously investigated using unpartitioned blades and blades radially partitioned at 50-percent chord (references 1 and 2, respectively). The 50-percent partitioned blade provided icing protection with a heating rate one-third less than that required for the unpartitioned blade; and the chordwise blade-surface temperature distribution was somewhat improved although midchord surface temperatures were very high, particularly on the inboard sections. Further heat economy seemed possible through the use of a more restricted passage in the blade.

The effectiveness of the 25-percent partitioned blade as a heat exchanger, the blade-surface temperatures and their distribution, and the icing protection afforded the propeller as evidenced by photographs, were investigated in the NACA Cleveland icing research tunnel and are reported herein.

## APPARATUS AND INSTRUMENTATION

The icing research tunnel used for the propeller-icing studies is a return-type tunnel in which icing conditions were simulated by means of water sprays and refrigerated tunnel air. The propeller installation (fig. 1) was placed in the diffuser section of the tunnel where a liquid-cooled engine mounted in an airplane fuselage was used to drive the propeller. A production-model four-blade propeller, 10 feet, 2 inches in diameter, modified for the internal passage of heated air was used. The air-heating system is shown in figure 2.

The instrumentation provided for measurement of tunnel and propeller operating conditions, propeller heated-air temperatures and mass flow, and blade-surface temperatures. Chordwise surface temperatures were obtained on two of the four blades at the 40- and 70-percent radial stations shown in figure 3. Complete details of the propeller installation together with instrumentation particulars are presented in reference 1.

Blade partitioning. - The partitions used within the blades were similar to those used in the 50-percent partitioned blades described in reference 2. The semirigid fiber-glass partitions, which were installed as shown in figure 3, confined heated air forward of approximately 25-percent chord. They were anchored and sealed at the blade shank and held in position radially along the blade by means of rivets through the blade walls. Partitions of semicircular form were used to fit firmly against the blade walls in order to prevent air leakage between the heated and unheated portions of the blade cavity. Each partition terminated approximately 6 inches from the blade tip to allow the heated air to pass to the rear of the blade and escape through the tip orifice.

Propeller-blade heating system. - The system used for supplying heated air to the propeller was essentially the same as that used for the 50-percent partitioned blades described in reference 2. The heated air entered each blade through a single shank inlet and was discharged through a tip orifice, which was approximately one-third the cross-sectional area of that used for unpartitioned blades. (See fig. 4.) A significant quantity of air leaked from the manifold to the tunnel past the graphite seals at the spinner periphery and at the blade shanks for which a correction was applied according to the calibration given in reference 1 for air leakage. Because the design air flow for the 25-percent partitioned blades was relatively low, it was impossible to obtain the desired heated-air temperature at the blade shanks utilizing the equipment originally provided for unpartitioned blades. Some increase in blade-shank air temperature was obtained, however, by bypassing additional heated air through the stationary manifold to compensate partly for the heat loss in the system. Propeller-blade air flow was then determined by subtracting the leakage past the seals and the air flow bypassed through the manifold from the total air flow supplied to the system.

## CONDITIONS AND PROCEDURE

Tunnel conditions. - The propeller was subjected to icing conditions at tunnel-air temperatures between -4° and 23° F. The tunnel-air velocity averaged approximately 200 feet per second measured at 75-percent propeller radius. During the icing period, the airspeed became less because of pressure losses resulting from tunnel ice formations. Liquid-water concentrations were approximately 0.1 gram per cubic meter at 3° F and 0.8 gram per cubic meter at 19° F. The droplet diameter based on the volume maximum averaged approximately 55 microns for all tunnel conditions. This value is larger than average droplet diameters usually found in the atmosphere. The icing of propeller blades, however, is not greatly reduced unless relatively small droplet diameters are encountered, because the collection efficiency of small bodies is approximately 100 percent. For the conditions used, the heating values required in this investigation are considered conservative.

Range of propeller variables. - The propeller was operated at blade angles of 28° and 35°, measured at 75-percent radius, with corresponding rotational speeds of 1050 and 850 rpm at which advance ratios of 1.1 and 1.4, respectively, were established to approximate the advance ratio of peak efficiency. At 1050 rpm, the heated air flow was approximately 92 pounds per hour per blade and at 850 rpm, 77 pounds per hour per blade.

Typical procedure. - Data were obtained during 10-minute periods of simulated icing conditions. Prior to each icing period, data were recorded for 2 minutes with all operating conditions stabilized and heated air flowing through the blades. Blade-surface temperatures were recorded at approximately 1 minute intervals throughout the preicing and icing period. Following each icing condition, residual icing photographs were obtained.

## RESULTS AND DISCUSSION

### Blade Heating System

More effective utilization of the heat supplied was realized by use of the 25-percent partitioned blades than by either the unpartitioned or 50-percent partitioned blades. A comparison of the blade heat-exchanger effectiveness for the three types of blade is given in the following table:

| Type of blade | Heating rate (Btu/(hr) (blade)) | Air flow (lb/(hr) (blade)) | Effectiveness (percent) |
|---|---|---|---|
| Unpartitioned | 32,500 | 450 | 47 |
| 50-percent partitioned | 19,000 | 265 | 56 |
| 25-percent partitioned | 6,600 | 92 | 77 |

The values in the table are all based on a shank air temperature rise of 300° F above tunnel ambient temperature at a propeller speed of 1050 rpm. The values for effectiveness were obtained for bare blades under no-spray conditions. Partitioning the blade at 25-percent chord increased the effectiveness to 77 percent as compared to 56 percent for the 50-percent partitioned blade (reference 2) and 47 percent for the unpartitioned blade (reference 1). The increase in effectiveness is caused by the concentration of the heated air at the leading edge of the blade where heat-transfer coefficients are high (reference 3). The section of the blade aft of the partition acts as a large sink for heat dissipation through the metal walls to the rear of the blade.

The maximum heating rate available with the air heating system was considerably less for the 25-percent partitioned blades than for the blades of the other two types because of the greatly reduced air flow. This heating rate was insufficient to provide adequate protection under the most severe icing conditions.

## Blade-Surface Temperatures

The blade-surface temperature distribution for the 25-percent partitioned blade was determined from the temperature data in the same manner as described in references 1 and 2. The range of heating rates in this investigation was limited, and almost no change in surface temperature was found at a propeller speed of 850 rpm when the heating rate was raised from 6500 to 8500 Btu per hour per blade. A maximum difference in surface temperatures of 4° F was observed at a propeller speed of 1050 rpm when the heating rate was increased from 8000 to 10,000 Btu per hour per blade.

The chordwise blade-surface temperature rise above tunnel ambient temperature for the three types of blade (25-percent partitioned, 50-percent partitioned, and unpartitioned) is shown in figure 5 plotted against distance from the leading edge on both the camber and thrust faces, at the 40-percent and 70-percent radial stations. These results are for icing conditions at a propeller speed of 850 rpm with heating rates of 8000, 14,000, and 35,000 Btu per hour per blade for the three types of blade, respectively.

The comparison of the surface temperature rise for the three blade types at 40-percent radius (fig. 5(a)) shows that the 25-percent partitioning was more effective in raising the temperatures near the leading edge with respect to the adjacent chordwise surface temperatures. The maximum temperature near the leading edge was greater than for the rest of the blade except far back on the thrust face. Such a distribution indicates a dissipation of much of the heat near the leading edge where it is most needed for ice prevention rather than on rearward surfaces on which heating is not so essential except for prevention of runback icing. Icing that results from water runback would be prevented by such a heat distribution if sufficient heat were supplied to prevent icing at the leading edge.

A heating rate of 8000 Btu per hour per blade in a 25-percent partitioned blade afforded more ice protection to the leading-edge region and much of the camber face than did 14,000 Btu in a 50-percent partitioned blade. The unpartitioned blade with 35,000 Btu per hour had surface temperatures generally higher than either of the two partitioned blades, although the peak near the leading edge in the case of the 25-percent partitioned blade appeared to exceed the temperature level in the same region for the unpartitioned blade.

It can be seen from figure 5(b) that at 70-percent radius the surface temperatures of the 25-percent partitioned blade are very little less than those of the 50-percent partititioned blade at the corresponding heat inputs previously given; whereas the surface temperatures fall as much as 34° F below those for an unpartitioned blade with almost four and one-half times the heating rate. The 2° F rise for the 25-percent partitioned blade at the leading edge fails to account for any appreciable part of the kinetic rise that would be expected in this region.

The similarity of the chordwise temperatures at the 70-percent radius for the 25- and 50-percent partitioned blades may be attributed to the large dissipation of heat rearward of the partition in the case of the 50-percent partitioned blade. So much heat was dissipated at the inboard sections that the amount of heat available at 70-percent radius for both the 25- and 50-percent partitioned blades was apparently almost equal.

The conduction of heat through the blade metal radially from the hub as well as chordwise from the air-heated forward portion is well illustrated in the case of the 25-percent partitioned blades where significant temperature rises above tunnel ambient temperature were observed on the blade surfaces considerably aft of the partition.

It has been pointed out that the temperature rises at 70-percent radius using 50- and 25-percent partitioned blades are similar for heating rates of 14,000 and 8000 Btu per hour per blade, respectively. (See fig. 5(b).) Because icing over this region would be detrimental to the aerodynamic performance of the propeller, and because 14,000 Btu per hour per blade was considered inadequate for protection of the 50-percent partitioned blade at 850 rpm, it is concluded that a heating rate of 8000 Btu per hour per blade is insufficient to afford icing protection for a 25-percent partitioned blade at 850 rpm under severe icing conditions.

## Flow Conditions over Blade Surfaces

The inflections shown in the curves of figure 5 were caused by changes in the flow over the blades. Near the leading edge the flow changed rapidly, accounting for the peaks on the 25- and 50-percent partitioned blades at 40-percent radius (fig. 5(a)). The inflections farther aft on the thrust and camber faces are caused by transition from laminar to turbulent flow.

The inflections of the curves indicate transition points on both faces at the 40-percent radius for the 25- and 50-percent partitioned blades; whereas the further addition of heat in the case of the unpartitioned blade stabilized the boundary layer to such an extent that laminar flow probably existed over the entire blade. (See fig. 5(a).) At the 70-percent radius (fig. 5(b)), the transition points are more pronounced, especially in the case of the 50-percent partitioned blade, and have moved much closer to the leading edge, as in the case of the 25-percent partitioned blade because of the increase in the Reynold's number of the boundary layer.

## Icing Observations

Photographs of residual ice formations after a 10-minute icing period at a propeller speed of 850 rpm are shown in figure 6. A comparison of the de-icing effectiveness of the 25-percent partitioned blades is presented for two tunnel ambient-air temperatures with rates of heat input averaging 7000 Btu per hour per blade in each case. These results indicate adequate blade heating at 23° F (fig. 6(a)), but insufficient protection at 15° F (fig. 6(b)). No icing observations were obtained at 23° F and a propeller speed of 1050 rpm.

A comparison of the photographs of residual icing on 25- and 50-percent partitioned blades (figs. 6(b) and 6(c)) with heating rates of 7000 and 14,000 Btu per hour per blade, respectively, indicates that surface temperatures at 40-percent radius near the leading edge were in each case near 32° F, although only one-half the rate of heating was used for the 25-percent partitioned blades The approximate equality of surface temperatures at the leading edge is also shown on the surface-temperature-distribution curves (fig. 5(a)). With the higher heating rate, the 50-percent partitioned blade caused excessive surface heating aft of the leading edge.

The blade-surface temperatures near the leading edge at 70-percent radius also appear to be marginal with respect to the freezing level, as indicated by the reformation ice layers near 70-percent radius shown in figure 6(b). Although the leading edge was marginally protected for these conditions, the flat chordwise temperature distribution contributed to a greater chordwise extent of icing with 25-percent partitioned blades than with the other configurations when leading-edge temperatures in each case fell below 32° F.

Lack of heat on the rear part of the 25-percent partitioned blade allowed runback icing over the thrust face on the outboard sections at 15° F ambient temperature. If sufficient heat were supplied, however, by using shank air temperatures higher than those obtainable in this investigation, to maintain a satisfactory ice-free leading-edge area, the surface temperature distribution would indicate probable protection from runback icing.

## SUMMARY OF RESULTS

From an investigation conducted in the NACA Cleveland icing research tunnel using internally air-heated propeller blades partitioned to confine the air forward of 25-percent chord, the following results were obtained:

1. A heating rate of 7000 Btu per hour per blade at a shank air temperature of 400° F provided sufficient icing protection for a propeller speed of 850 rpm at an indicated tunnel-air temperature of 23° F but was insufficient to prevent icing at 15° F.

2. Surface temperatures indicated satisfactory chordwise distribution of the applied heat so that if sufficient heat were provided for icing protection at the leading edge, the rearward surfaces would be protected without excessive surface heating.

3. Heat-exchanger effectiveness was increased to 77 percent from average values of 56 percent for the 50-percent partitioned blades and 47 percent for unpartitioned blades.

## CONCLUSIONS

The high heat-exchanger effectiveness associated with the 25-percent partitioned blades and the lower heat-input rate required as compared to the unpartitioned and 50-percent partitioned blades indicate that partitioning the cavity at approximately 25-percent chord provides the most economical method of those examined for air-heating propeller blades. If heat were supplied to the blade at a sufficient rate to maintain satisfactory leading-edge temperatures and surface temperatures near the rear of the blade were not raised adequately to prevent runback icing under all conditions, part of the heated air could be bled to the rear chamber through orifices in the partition without destroying the concentration of heat at the leading edge.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, January 19, 1948.

## REFERENCES

1. Mulholland, Donald R., and Perkins, Porter J.: Investigation of Effectiveness of Air-Heating a Hollow Steel Propeller for Protection Against Icing. I - Unpartitioned Blades. NACA TN No. 1586, 1948.

2. Perkins, Porter J., and Mulholland, Donald R.: Investigation of Effectiveness of Air-Heating a Hollow Steel Propeller for Protection Against Icing. II - 50-Percent Partitioned Blades. NACA TN No. 1587, 1948.

3. Gray, V. H., and Campbell, R. G.: A Method for Estimating Heat Requirements for Ice Prevention on Gas-Heated Propeller Blades. NACA TN No. 1494, 1947.

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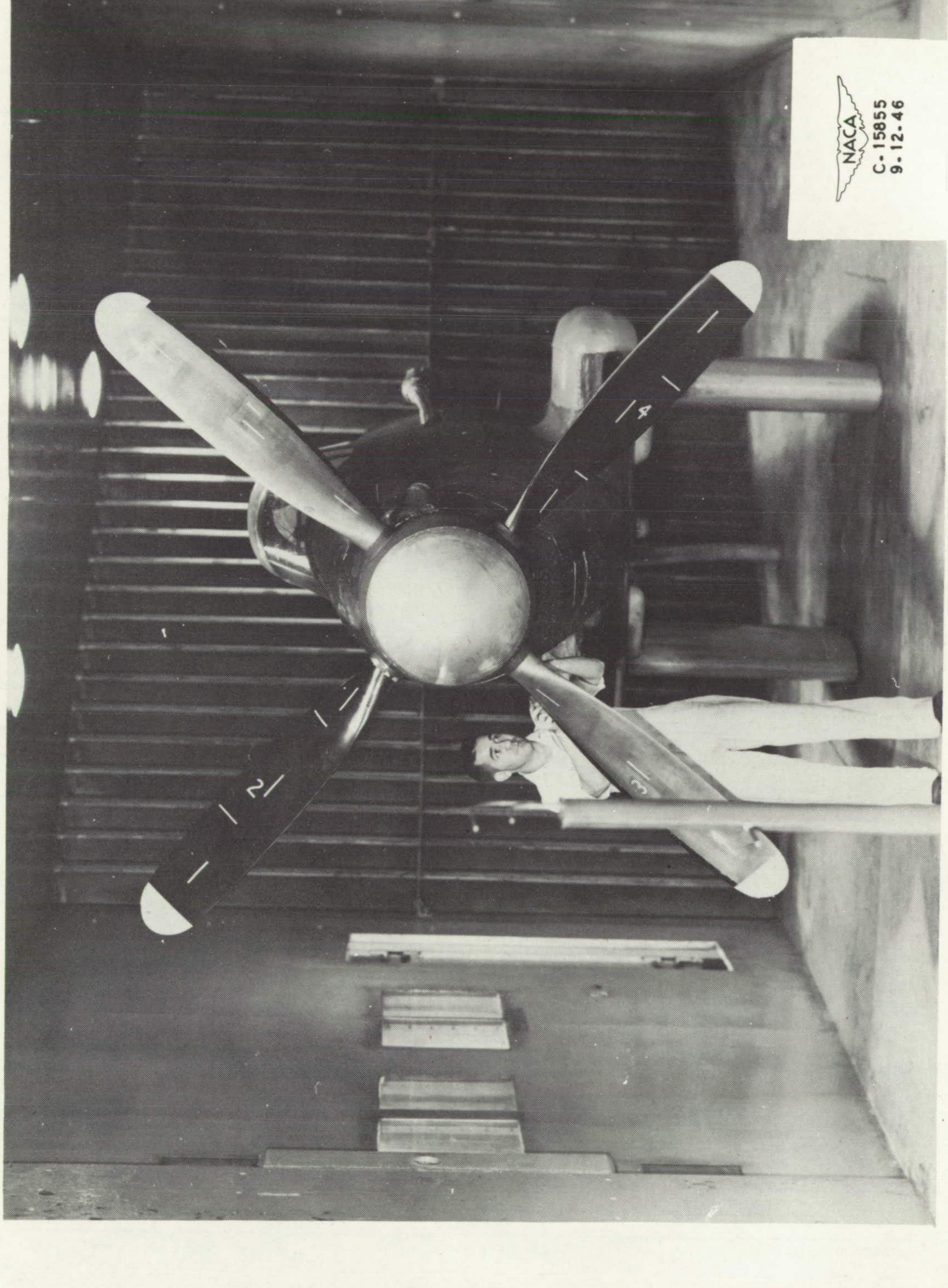


Figure 1. - Tunnel installation of air-heated hollow steel propeller for icing investigation.

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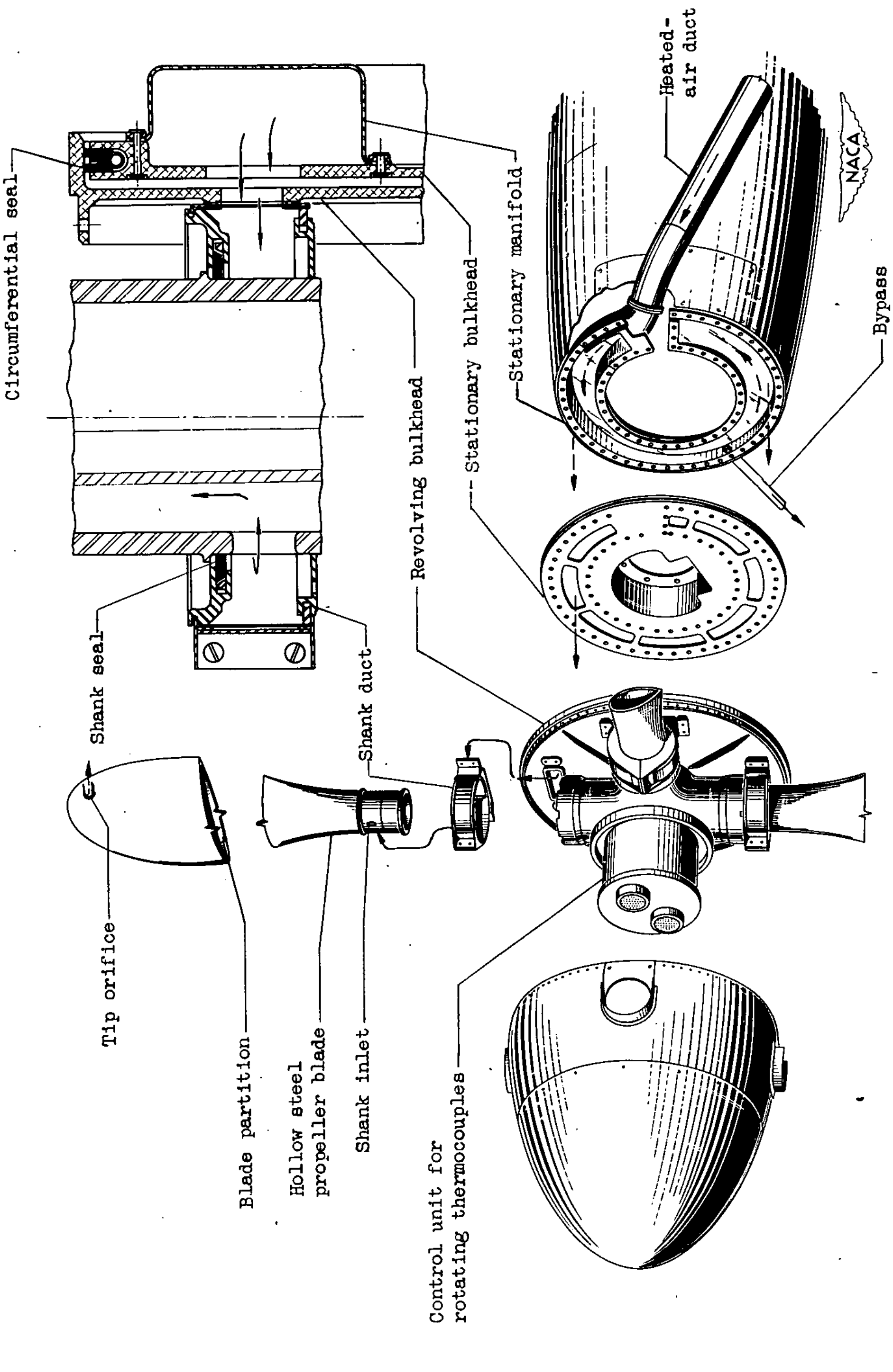
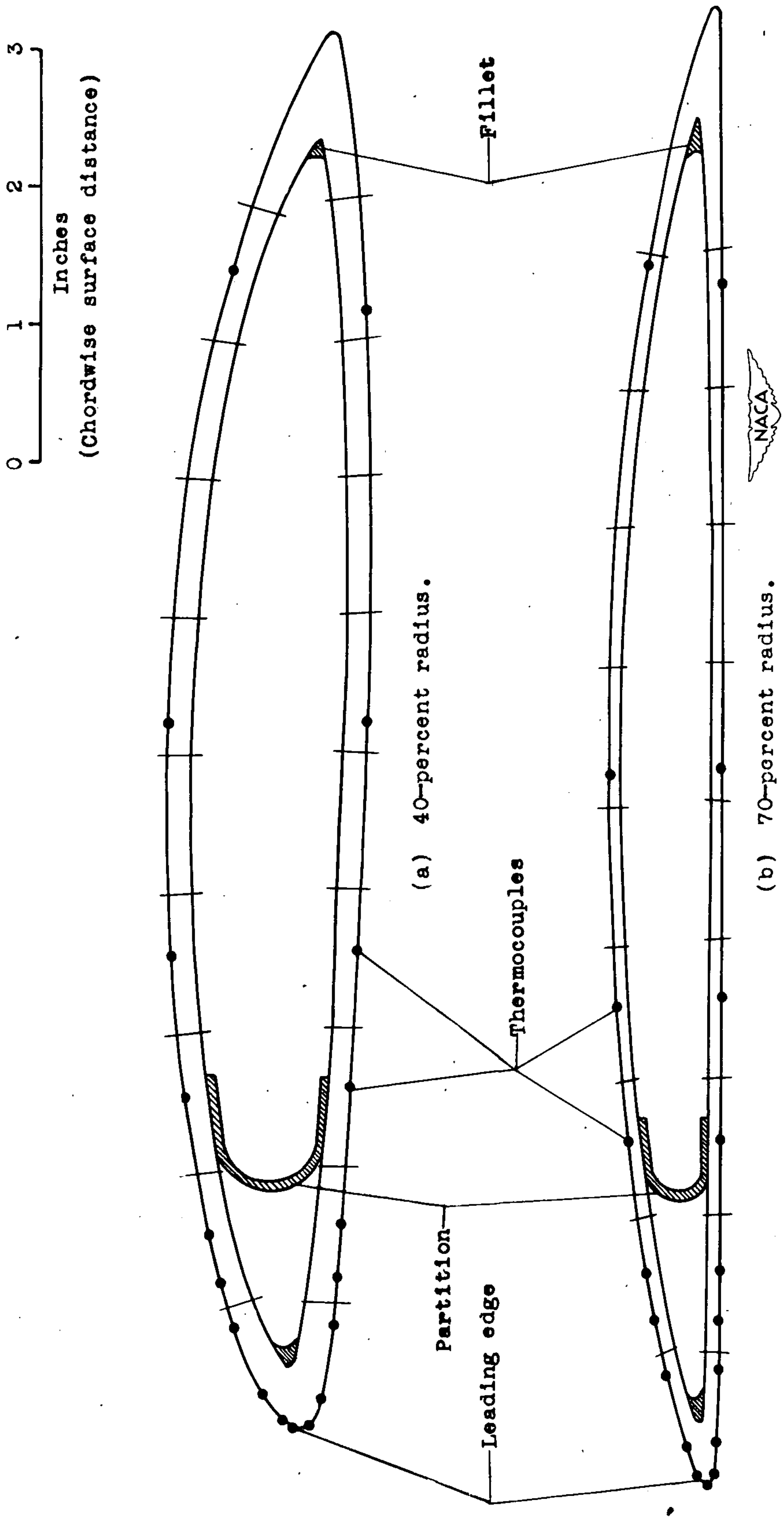


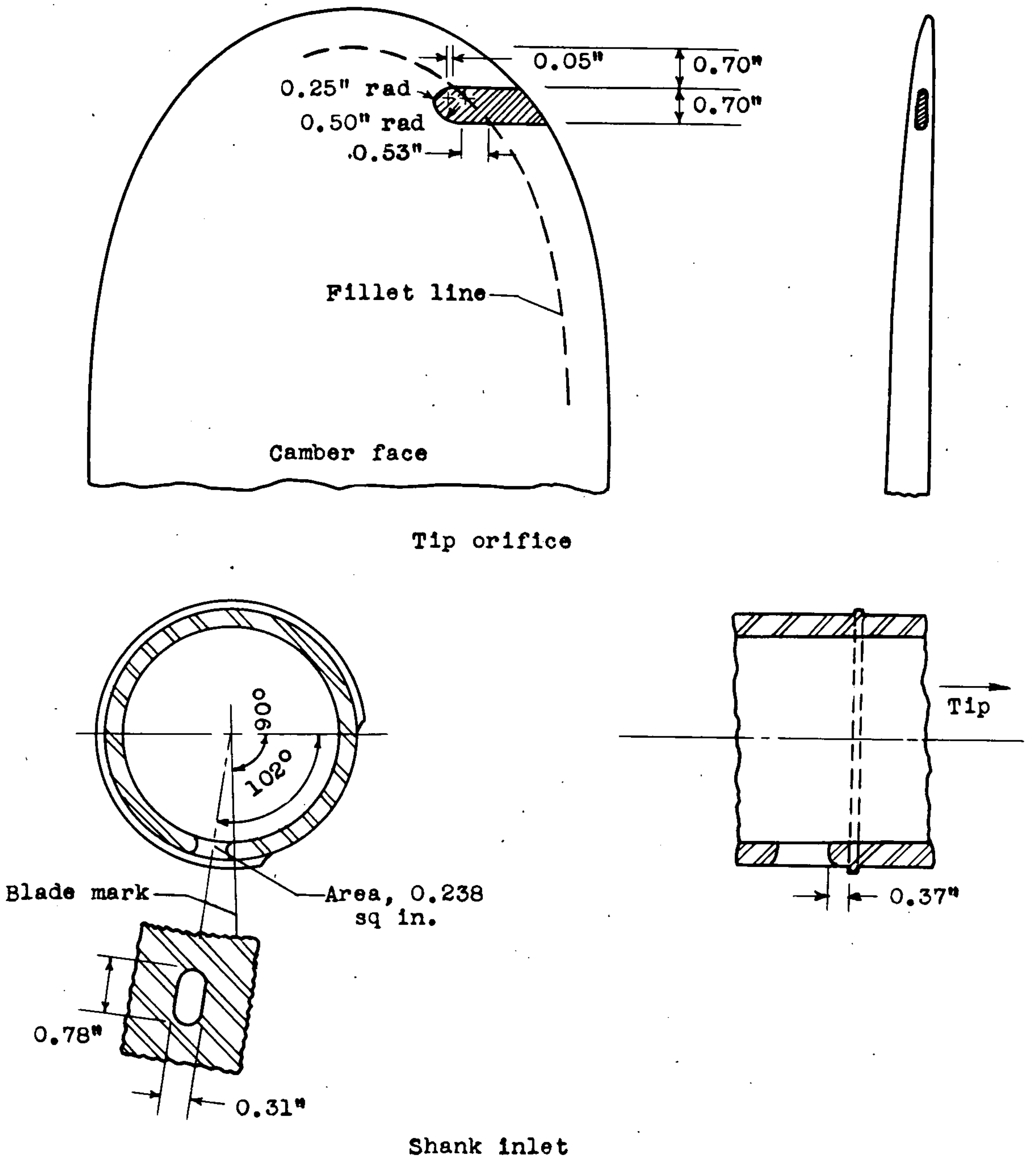

Figure 2. - Details of air-heated propeller installation.




(a) 40-percent radius.

(b) 70-percent radius.

Figure 3.- Chordwise thermocouple locations.




(a) Construction details.

Figure 4.- Shank inlet and tip orifice for 25-percent partitioned air-heated propeller blades.

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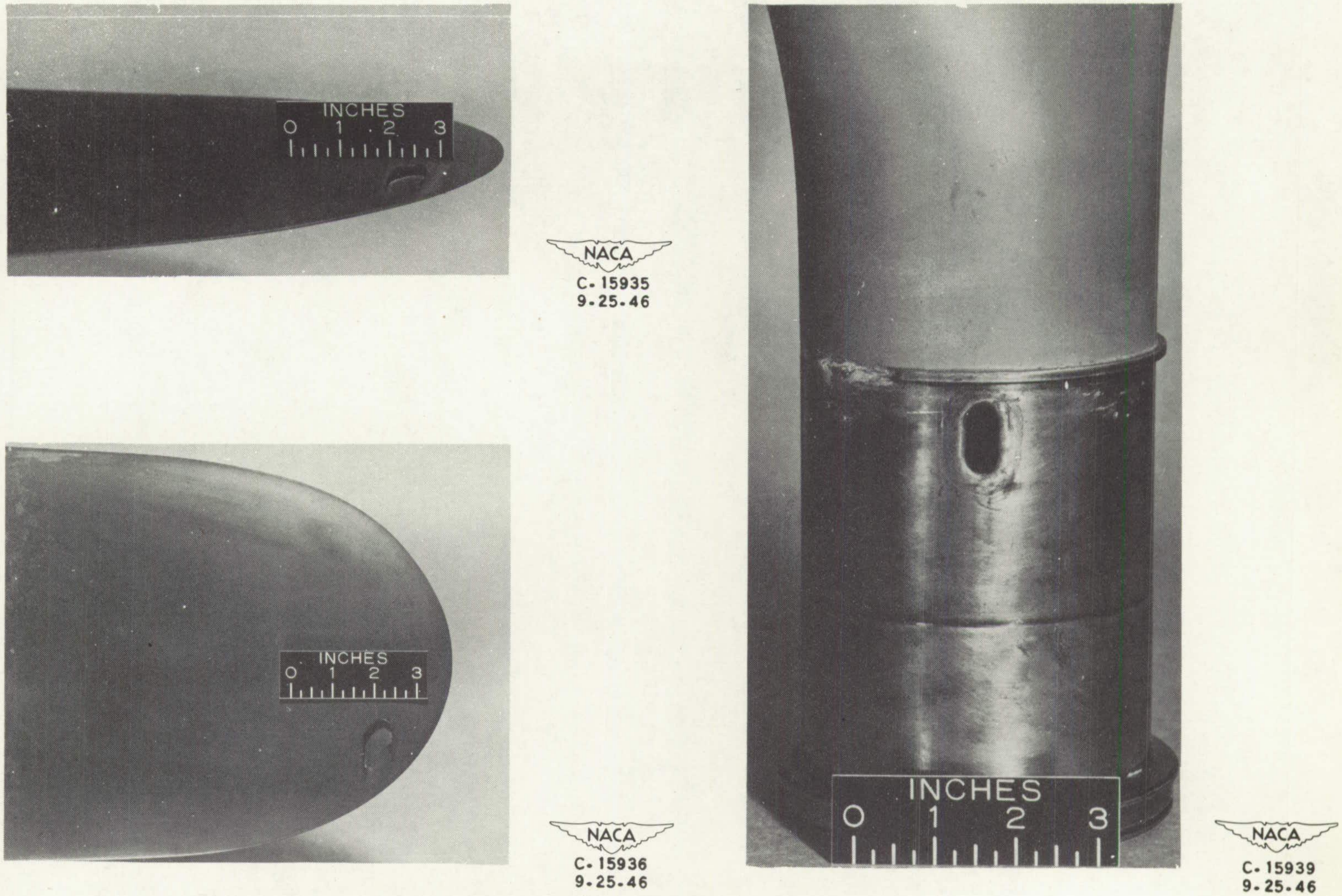


(b) Photographs of tip and shank openings in blade.

Figure 4. - Concluded. Shank inlet and tip orifice for 25-percent partitioned air-heated propeller blades

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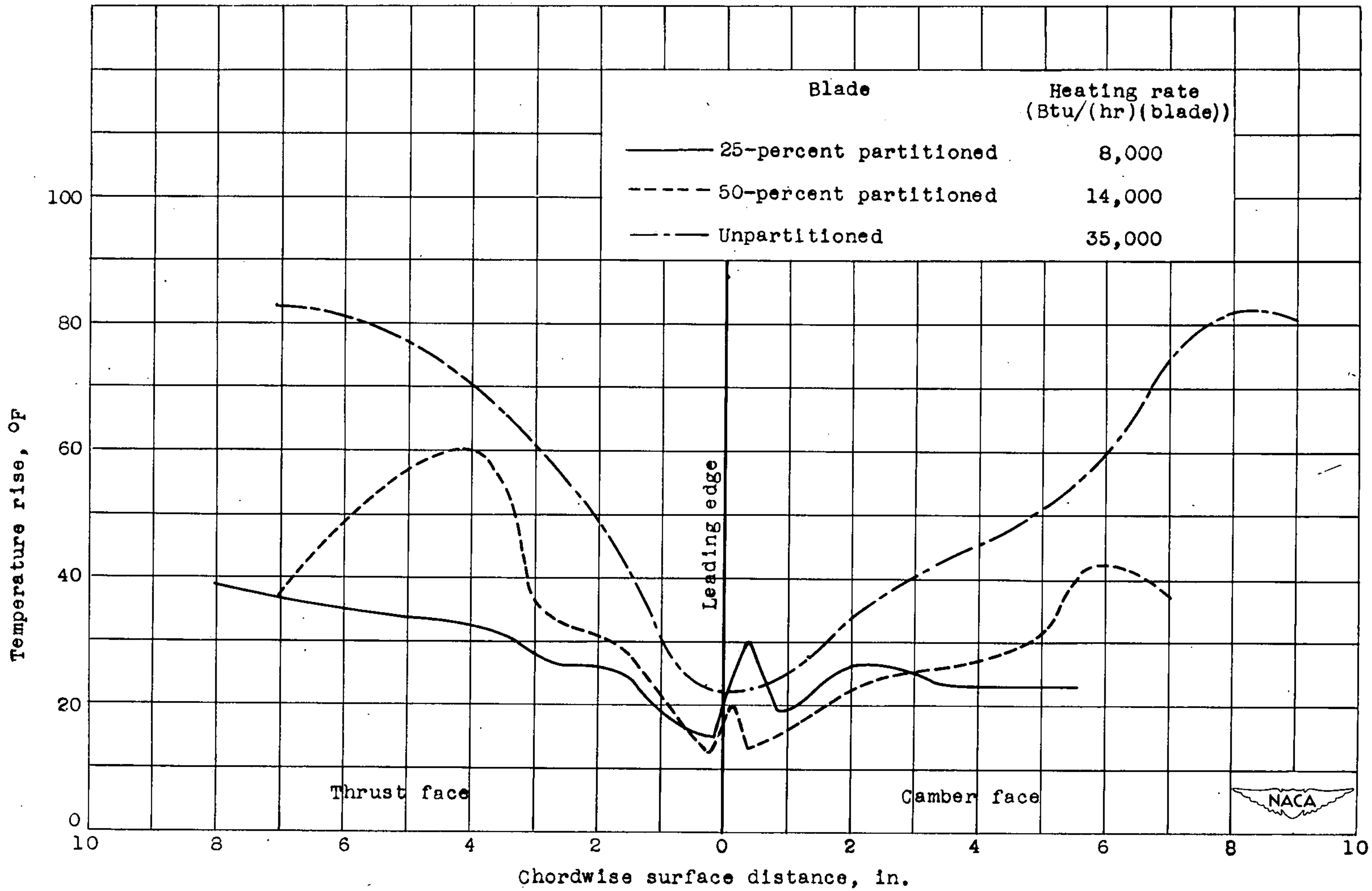
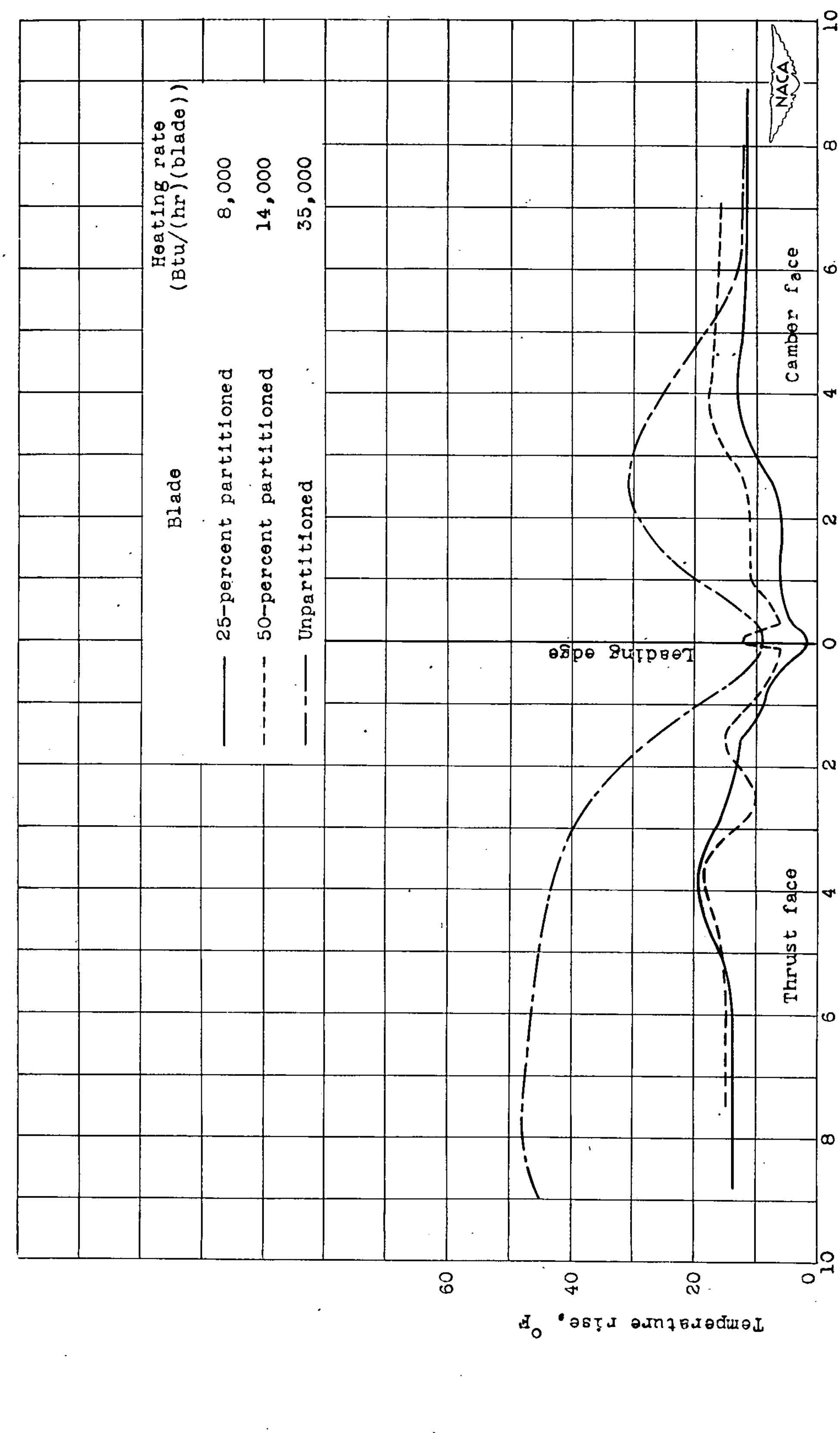



(a) 40-percent radius.

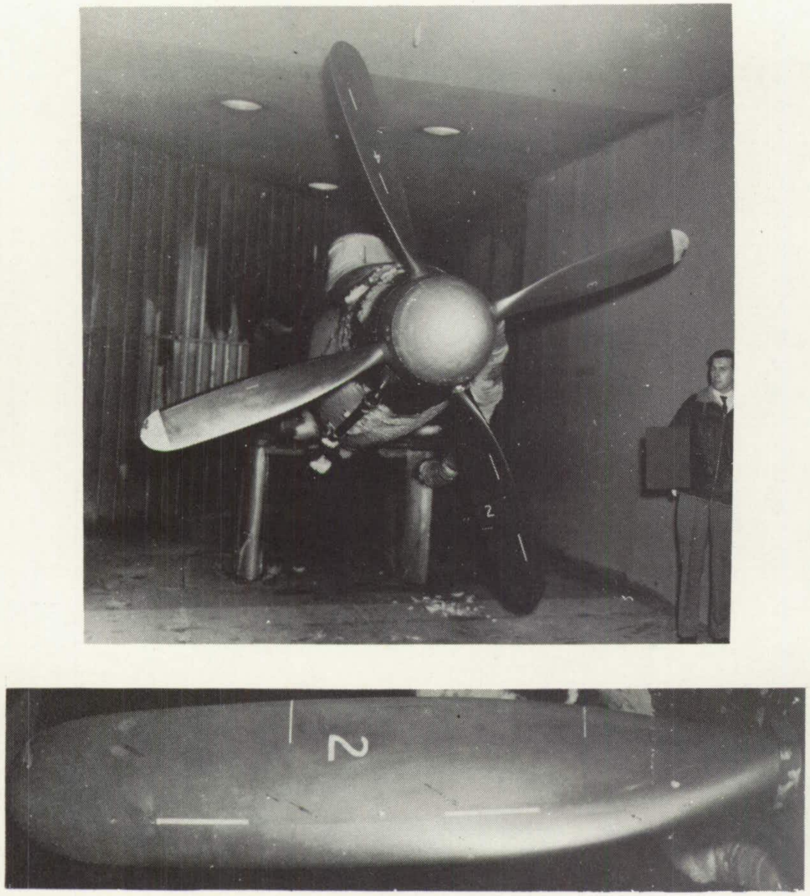
Figure 5.- Blade-surface temperature rise above tunnel air temperature for three types of air-heated propeller blade with different heating rates under icing conditions. Blade angle, 35°; propeller speed, 850 rpm.



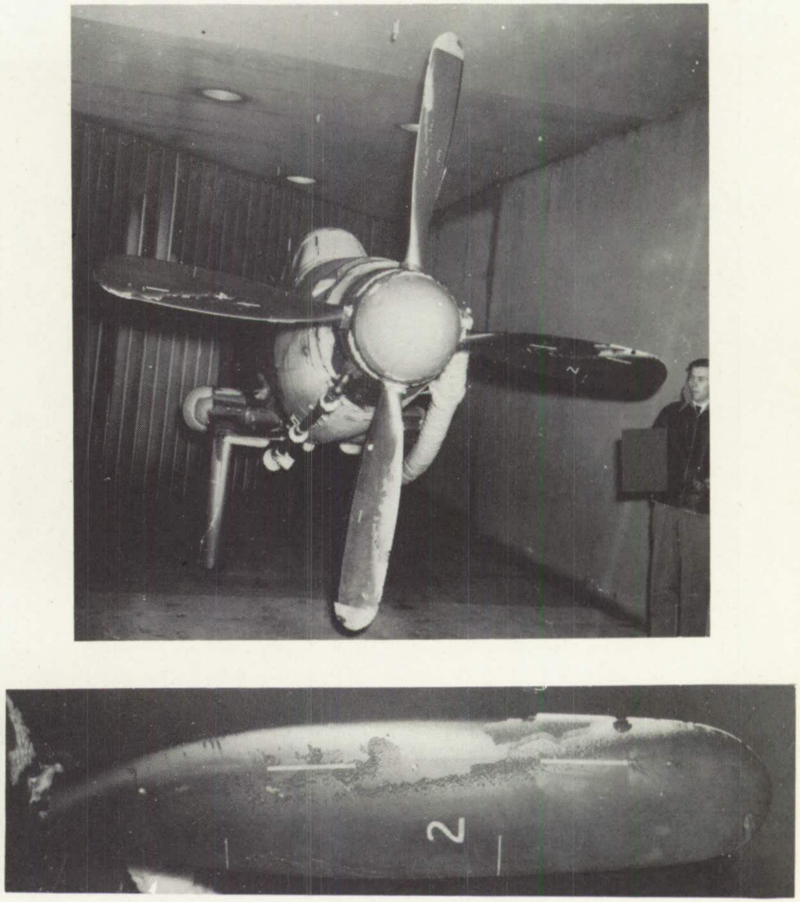

Chordwise surface distance, in.

(b) 70-percent radius.

Figure 5.- Concluded. Blade-surface temperature rise above tunnel air temperature for three types of air-heated propeller blade with different heating rates under icing conditions. Blade angle, 35°; propeller speed, 850 rpm.



(a) 25-percent partitioned blade: indicated tunnel air temperature, 23° F; heating rate, 7000 Btu per hour per blade.



(b) 25-percent partitioned blade: indicated tunnel air temperature, 15° F; heating rate, 7000 Btu per hour per blade.

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Figure 6. - Residual ice formations on propeller blades following 10-minute icing period. Blade angle, 35°; propeller speed, 850 rpm.

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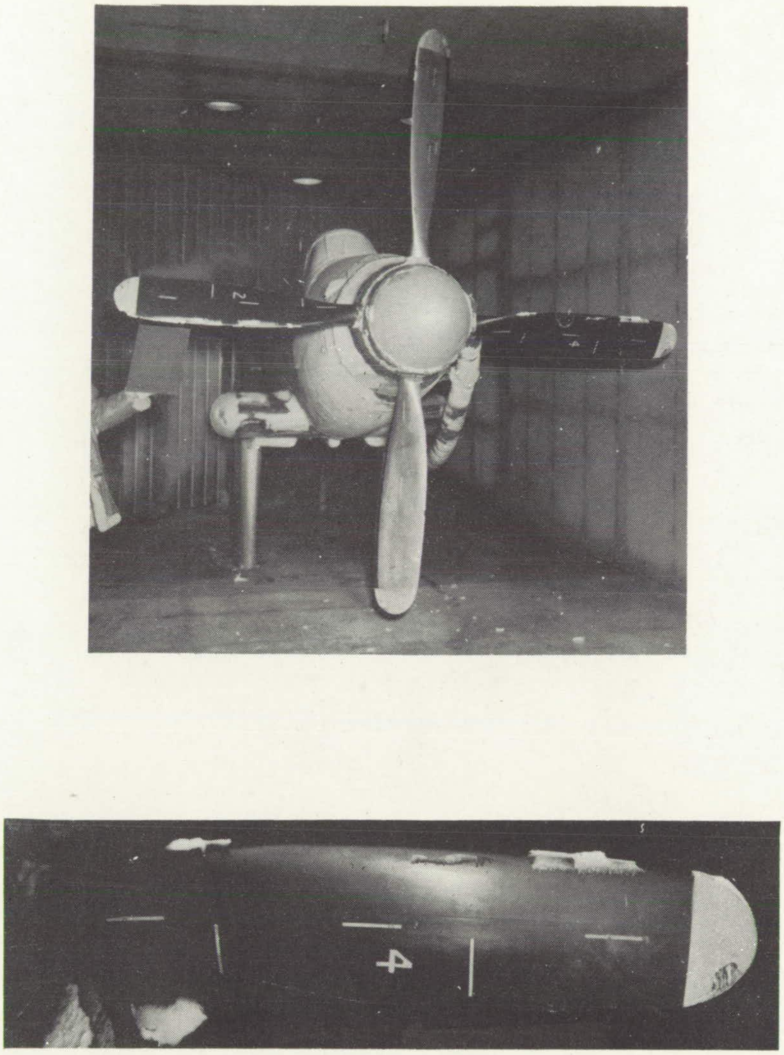


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(c) 50-percent partitioned blade: indicated tunnel air temperature, 13° F; heating rate, 14,000 Btu per hour per blade.

Figure 6. - Concluded. Residual ice formations on propeller blades following 10-minute icing period. Blade angle, 35°; propeller speed, 850 rpm.